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ABSTRACT

The usefulness of "memory" is being questioned as a concept for explaining the facts of remembering. The brain is an extensive and elaborate switching system for organizing sensory inputs from environmental situations and for generating appropriate and properly timed responses to them. The learning of knowledge consists of learning a performance--an "imagery talk-about" used to initiate, edit, and describe the related imagery schemas. This view of how the brain works asserts that what is experienced as "memory" is in fact a side effect of building and modifying schemas for performing in the situations presented. Implications for the practice of instructional technology include the following: (1) instructional programs should be designed to prepare students to perform effectively in future life and job situations; (2) if people are to perform effectively in future situations, appropriate sensory representations must be built into the schemas they will use when they are actually in those situations; and (3) "imagery talk-abouts" must be derived from the future performance situations under appropriate feedback conditions during learning. (Eight figures are appended.) (YLB)

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HOW BRAINS WORK

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HOW BRAINS WORK.

WHY DO WE NEED TO KNOW ANYTHING ABOUT HOW BRAINS WORK?

The brain is where the action is in learning. It is in the brain that the changes occur that produce learning. But knowing something about how brains work will not necessarily make you a better instructional developer.

1. There are some traditional myths and half-truths about how brains work that can be very misleading in the design of instruction. We need to replace these myths and half truths with more accurate conceptions of how brains work.

2. There are recurring fads to which we are subjected declaring some magical approach to instruction or some aspect of human performance based on some astounding finding or theory about how the brain works. We need to be able to sort out fact and solid reasoning from wishful thinking and fancy so that we don't damage our own practice or damage our clients.

If you are already a performance-oriented developer, knowing something about how brains work might ward off the latest psychobabblers, neurobabblers, and computerphiles from you and your clients.

If you are a subject-matter oriented developer, then knowing how brains work might help you repent and change your ways.

If you are a psychobabbler, a neurobabbler, or a computerphile, then knowing something about how brains work may help you overcome your belief in magic.

We don't need to become full fledged neuropsychologists. But a <u>little</u> neuropsychology and a <u>lot</u> of common sense can go a long way towards helping develop some more <u>useful</u> conceptions of <u>how</u> brains work than most of us now have.

THE BRAIN METAPHORS AND IMPLICATIONS INVENTORY.

Before we go on, let's record our present <u>conceptions</u> and <u>misconceptions</u> about how brains work. I have prepared an inventory of common conceptions and misconceptions. Take a few minutes now to record your present views

about the brain. Read each entry in the BRAIN CONCEPTIONS AND MISCONCEPTIONS INVENTORY and indicate whether you agree or disagree with it.

If you want to qualify your selection, please do so. Make all the notes you want on the sheet. I'm not going to collect them. They are to help you identify your present conceptions. At the end of the session, we'll go over these items one by one and I'll solicit your questions and comments at that time.

	AGREE/DISAGREE
1. Like computers, brains are organized into two parts -- programs (thinking) and files (memory). A program recalls information from memory, compares it to sensory inputs from the immediate environment, generates a difference signal, and uses the difference signal to call up some other program routine.	A / D
2. The principal function of the brain is to serve as a repository for knowledge. It is a massive storage device full of information files.	A / D
3. There are many different kinds of memory within the human brain -- iconic memory, short term memory, and long term memory. Long term memory, in turn, consists of several more specialized memories: procedural memory, semantic memory, episodic memory, and perhaps others.	A / D
4. Information in memory can be remembered in any situation in which it's needed.	A / D
5. The brain contains "centers" which store and process language, reasoning, mathematics, spatial relations, music, and so on.	A / D

6. Information can be moved around from one memory in the brain to another or to different places in the same memory. A / D

7. Information is stored in memory much like it is organized in library stacks; that is, by topics. A / D

8. The brain contains a retrieval system that allows it to find information in memory when needed. A / D

9. Everything that has ever happened to us or that we have ever done is stored in our memories. A / D

10. Under the right conditions, we can recall anything that has ever been in our memory. A / D

11. Human brains are radically different from the brains of other mammals: They have some different structures that perform different functions. A / D

12. Education consists principally of putting "knowledge" into students' memories: Training consists principally of putting "skills" into their memories. A / D

13. The average person only uses about 10 percent of his or her brain. A / D

The view of how the brain works that I will describe **disagrees** to a substantial degree with <u>every one</u> of the entries in the inventory you just

filled out. This view is based on well established and conservative views of the underlying neurology of how information exists in the brain.

Before we start, let me tell you where we're going this morning. Here are the issues we will examine:

1. How is **information represented** in the brain? The answer to this question tells us what kinds of metaphors and models make sense and what kinds don't. It also bears on what we believe about human memory.

2. What **criteria** should be met by a concept of how brains work? Without criteria, we can't tell where we're going or how to get there.

3. What is the **overall function** performed by the higher levels of the brain for living creatures? What does it do?

4. What are the important **physical characteristics of the brain** which we need to consider?

5. What is the basic **functional unit** of the brain?

6. How are the basic **functional units organized**?

7. How does **language** fit into our model?

8. How do we account for what appears to be **memory**?

9. How about **traits, faculties, and bumps** on the head? These are fads that keep coming back to plague us in new and different guises. But they are still the same old nonsense. Let's come to understand them once and for all and put them to rest forevermore.

10. What **implications** does all this have for the practice of instructional technology?

THE BASIC ISSUE.

Information is represented in brains in a very different way than it is in man-made computers. In man-made computers the same piece of information can be stored in any of many different registers or locations in memory. Information in computers exists as a pattern of energies that is independent of **where** that pattern is stored. However, information in brains was identified in the late forties by the neuropsychologist, Donald Hebb[1], as depending upon the excitation of a pattern of specific cells in the brain. This has been the prevailing view in neuropsychology since then and still is today.

This difference in how computers and brains work places significant constraints on our use of a computer analogy to help us understand how brains process information. Computers can move information from one place to another, they can process it in different ways and store the results in different places. Meaning is contained in the pattern of energies and the pattern can be moved around from place to place. In brains, however, meaning is contained in the pattern of specific cells that are excited. Such meanings cannot be moved from one place to another.

The view of how the brain works that I will describe most particularly challenges the usefulness of the concept of **memory**. As if one memory were not enough with which to come to grips, textbooks in cognitive psychology describe many different kinds of memory within the human brain -- iconic memory, short term memory, and long term memory. Endel Tulving[2] further breaks long term memory into procedural memory, semantic memory, and episodic memory. He speculates that there may be an untold number of other memories yet to be "disccvered." Got a new kind of information that doesn't quite fit into known memories? Don't worry about it. We'll invent a new kind of memory.

Multiple memory theories, such as Tulving's, might lead us to classify pieces of knowledge as belonging to this or that memory system. But that doesn't improve our instructional designs. Multiple memory theory is one more taxonomy. And instructional technology has had many futile love affairs with various grandiose taxonomies. Taxonomies are like beautiful but frigid lovers: They enchant us but they fail to satisfy. Multiple memory

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[1] See Lloyd L. Avant and Harry Helson "Theories of Perception." Chapter 21 (page 434) in the Handbook of General Psychology, Benjamin B. Woolman, Editor. Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1973.

[2] Endel Tulving "How Many Memory Systems Are There?." American Psychologist, April 1985

theory is a theoretical approach that appears to me to be strained beyond repair at this point in time. But what can we put in the place of memory?

I'm certainly not the first person to question the usefulness of the concept of "memory." In fact, when I first came across a serious questioning of its usefulness in some material I was reading, I found the notion incomprehensible. It literally left me feeling dizzy and light headed for a period of several weeks as I tried to reconcile this radical challenge to concepts I had acquired over many decades and which are part of our culture. Several years ago, Ulric Neisser[3], who is sometimes credited with being the father of contemporary cognitive science, wrote as follows:

> **I think that "memory" in general does not exist . . . It is a concept left over from a medeival psychology that partitioned the mind into independent faculties: "thought" and "will" and "emotion" and many others, with memory among them. Let's give it up and begin to ask our questions in different ways. Those questions need not be uninformed by theory, or by vision of human nature, but perhaps they can be more closely driven by the characteristics of ordinary human experience.**

I'm are not questioning the facts on which memory theory is built. Rather, I'm questioning the usefulness of "memory" as a concept for explaining those facts. I'm saying we need a new analogy or metaphor for understanding how the brain works. We need a way of accounting for the facts of remembering without invoking concepts about physical or functional memories.

But if storing information in memory is not the principal function of the higher levels of the brain, then what on earth is the brain's principal function?

CRITERIA FOR A BRAIN MODEL.

Before we consider the principal function of the brain, let's set some criteria which must be met by any brain metaphor or model -- whether it be this one or some other one.

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[3] Ulric Neisser Cognition and Reality: Principles and Implications of Cognitive Psychology. W.H. Freeman and Company, San Francisco, 1976.

Whatever model of the brain we develop must meet three criteria:

1. The first criterion is that our model must be **parsimonious**; that is, it must be as simple and uncomplicated an explanation of how brains work as we can manage and still account for the major facts of what the brain does. The Law of Parsimony is an old law in science and perhaps the fundamental law to be observed in building good theory.

   This law has been stated in several different forms over the centuries. One of the oldest is known as Occam's Razor after William of Occam in 14th century England. A more recent version was formulated by Lloyd Morgan in the 1930s. It is known as Morgan's Canon. Basically, what these two versions of the Law of Parsimony say is that if you make a complicated mess of things in building your theories, Occam will cut your throat and/or Morgan will blow you to smithereens.

   Since none of us want either of these dire consequences to happen to us, we must get the most possible mileage out of the fewest number of explanatory concepts that we possibly can. We don't want to garbage up our model of the brain with unnecessary concepts.

2. The second criterion is that our model of the brain must be consistent with the principles of **evolution**. The basic functions and processes which we attribute to human brains we must also be able to attribute to the brains of all mammals. We cannot assume radical neurological discontinuity between human beings and the other mammals. Our brains are, at best, an enhancement of their brains.

3. The third criterion is that our model of the brain must be consistent with the known facts and principles of **neurology**. It must be built on known facts and principles regarding the physical structure and operation of the brain. For instance, a model that assumes that information can be moved about from one place to another in the brain is unacceptable because such an assertion is at variance with present day neurology. As it turns out, there are relatively few facts and principles of neurology that we need to consider.

WHAT DOES THE BRAIN DO?

Now let's get back to our earlier question: What overall function do the higher levels of our brains serve us and other mammals?

As far as brain morphologists can tell, all higher mammals possess the same major structures in their brains. The brains of different mammals differ principally in the relative size of a few specific structures. So whatever it is that brains do, they do pretty much the same thing in all higher mammals. So what could that be? Tigers and apes don't read books or study history. What could be the common function for which animals and humans both use the higher levels of their brains?

Richard Dawkins[4], the noted zoologist and ethologist, writing about evolution, refers to different species of living creatures as "survival machines" because they serve to insure the survival of genes. He tells us very clearly what general thing brains do for all creatures. He says:

> **The main way in which brains actually contribute to the success of survival machines is by controlling and coordinating the contractions of muscles. To do this they need cables leading to the muscles, and these are called motor nerves. But this leads to efficient preservation of genes only if the timing of muscle contractions bears some relation to the timing of events in the outside world. . . . For this reason, natural selection favoured animals which became equipped with sense organs -- eyes, ears, taste-buds etc. -- by means of cables called sensory nerves.**

In Dawkins view, brains are organs for perceiving the world around us and for directing and timing our movements through that world and our manipulation of objects in that world.

Well, you might be thinking, that's okay for animals. And it's certainly one thing that our brains do. But our brains do a lot more than just that. And you're right. However, a brain that can move us through our surroundings may also be quite capable of doing the special things that we do -- such as using language and symbols -- without having to have additional structures not found in the brains of other mammals. The Law of Parsimony requires that we explore this possibility before we start conjuring up special

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[4] Richard Dawkins The Selfish Gene. Oxford University Press, New York, 1976.

structures and processes to account for the performance differences between humans and other mammals.

THE PHYSICAL STRUCTURE OF THE BRAIN.

Let's start by reviewing some of the characteristics of the brain's physical structure.[5] From what kinds of parts is it made, how many are there, and how are these parts put together?

The human brain is made up of approximately 100 billion neurons.

Neurons are different from other cells in one very important respect: They transmit impulses along their length and transfer those impulses to other neurons. However, it takes more than one impulse to fire the next neuron. It can be many different impulses coming in from different neurons or repeated impulses from the same neuron or some combination of these two.

The average nerve cell in the brain makes from 10,000 to 100,000 connections with other cells. So there are many ways in which a neuron can receive enough impulses to fire it.

It's not just the number of connections that are important, but also the kinds of connections made between neurons. When a nerve cell fires, the chemical which it passes to the next neuron can lead to either a negative or positive potential in the next neuron.

Let me show you what happens in a neuron. Figure 1 shows a Rube Goldberg design for a neuron. There is a switch arm that is moved to the right or to the left by single notch increments by the action of two solenoids. Notice that negative inputs move the switch arm towards the firing contact and positive inputs move it away.

- If the potential is negative, it makes it easier for inputs from yet other cells to summate with it until it is sufficiently large to fire the target cell. It facilitates firing in the target neuron.

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[5] See the following sources for general information about the structure of the brain:
(1) Richard Restak, M.D. The Brain. Bantam Books, 1984.
(2) Robert Ornstein and Richard F. Thompson The Amazing Brain. Houghton Mifflin Company, Boston, 1984.
(3) The Diagram Group The Brain: A User's Manual. Perigee Books published by G.P. Putnam's Sons, New York, 1982.

- If the potential is positive, it makes it more difficult for negative potentials from other cells to summate sufficiently to fire the target cell. It inhibits firing in the target neuron.

These different effects make it possible to have a virtually unlimited number of different patterns of cells involving basically the same specific cells.

Figure 2 shows us what a gaggle of neurons in their native habitat really look like. Notice all the many connections among these neurons. Neurons can be connected to eachother in many different patterns.

Let's look at some of the basic patterns that could exist among neurons with these characteristics. These patterns are greatly simplified in that they show only one or two connections between neurons. But they give us some idea of the kinds of connections that can exist within an assembly of real neurons with thousands of connections between them.

Pattern A in Figure 3 shows a neuron firing repeatedly until its transmitted impulses summate in the second neuron and cause it to fire.

Pattern B shows two neurons firing together so that their impulses summate in the third neuron and cause it to fire. In this way, impulses coming from two different paths can **converge** to form a single path.

Pattern C also shows two neurons firing together, but in this case one causes a negative potential on the third neuron while the other causes a positive potential on the third neuron. As a result, the two firings **cancel** each other and nothing happens in the third neuron.

Pattern D shows a single neuron firing repeatedly until its impulses summate in two other neurons. In this way, impulses coming from a single path can **diverge** to form two separate paths.

Pattern E shows a neuron connecting to two other neurons in sequence. Firing of the first neuron causes the second neuron in the sequence to fire by transmitting negative impulses to it and blocks firing in the third neuron in the sequence by transmitting positive impulses to it. This **blocked transmission** pattern is important because it provides a means by which neurons corresponding to particular sensory imagery can be fired and the responses which typically follow such imagery can be inhibited. This is a key pattern for explaining how imagination or mental imagery develops. We'll come back to this point later.

Pattern F shows a **reverberatory circuit** which was first described by Lorente de No in the 1930s. In this version of the reverberatory circuit, the net also includes inhibition of later neurons in the net. The reverberatory circuit illustrates how a neural impulse can be kept going for a brief period of time until impulses from other parts of the brain can be coordinated with it. It could be one mechanism involved in so-called "immediate memory."

These patterns are indeed greatly simplified. Even the simplest of actions probably involves an assembly of neurons that includes thousands of most of these patterns combined into a very complex network.

THE FUNCTIONAL UNIT OF THE BRAIN.

Let's trace the activity in an assembly of neurons that performs a very simple function -- the perception of a simple visual pattern such as a geometric figure. I've borrowed the basic elements for this process from Ulric Neisser's[6] concept of a perceptual schema. A perceptual schema is an assembly of neurons connected nerves from sensory organs and to muscles and glands. In Neisser's words a perceptual schema "accepts information as it becomes available at sensory surfaces and is changed by that information; it directs movements and exploratory activities that make more information available, by which it is further modified." I'll suggest some simple neurology to show how the elements of a schema might be accomplished.

The activities in a typical assembly of neurons (see Figure 4) involved in processing a simple percept might well proceed in this way:

1. Energies from the surrounding environment lead to responses in sensory organs.

2. The responses in the sensory organs lead to the firing of sensory nerve cells which connect the particular sense organs to the brain.

3. These initial sensory inputs to the brain facilitate the firing of other neurons in the brain which also receive sensory inputs. In this way the brain anticipates the next round of sensory inputs.

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[6] Op. cit.

4. Nerve cells in the brain which connect to the active sensory nerves fire as a result of these initial inputs from the sensory nerves.

5. The firing of the initial cells causes a second array of cells to fire that produce **movements** that put particular sense organs in a better position to explore for and pick up additional stimuli from the environment. For instance, our eyes move and our head turns to trace the perimeter of a triangle or rectangle and count the corners in the figure.

6. The firing of the initial cells also causes the firing thresholds of other brain cells to be lowered. This allows the appropriate sensory nerves to fire these brain cells with less input than would otherwise be required. Lowering these thresholds is one way by which the brain **anticipates** the inputs that result from the stimulus seeking movements. We see here that there can be a neural mechanism for anticipating later sensory inputs in even those neuron assemblies concerned with very small, discrete percepts and movements. This sensory anticipation in larger neuron assemblies is one way in which we can account for positive reinforcement or positive consequences.

7. Yet other brain cells have their firing thresholds raised by the initial array of cells. This blocks inappropriate sensory inputs to this second array of cells. It limits the spread of activity in the brain.

What I have just described is some very plausible neurology which could underlie what happens in what Ulric Neisser calls a perceptual schema. The important thing to note about perceptual schemas is that they are initiated by **sensory inputs** and then generate **exploratory movements** and **anticipate** subsequent sensory inputs.

As perceptual schemas are used, they are changed. When a group of brain cells fire, they undergo biochemical changes that make it easier for them to fire the next time as a pattern.

If some sensory features of our environment occur more often than others, then those features will be more strongly represented in the perceptual schemas of our brains. Bits and pieces of stimulus patterns that don't occur very often or that tend to vary a great deal from one time to another will be "averaged" to some low level of strength or drop out of our schemas entirely.

Also, when brain cells are cut out of a schema by inhibitory potentials from other cells, it makes it more likely that they will be cut out the next time. In this way, we build perceptual and -- as we'll see in just a minute -- action schemas that have the greatest possible utility to us -- schemas that focus on the more likely inputs and disregard the less likely ones.

As shown in the block diagram in Figure 5, action schemas differ from perceptual schemas in only one respect: Instead of generating exploratoring actions for picking up additional anticipated stimuli, they generate response actions that have effects on the environment and anticipate the sensory effects of those response actions. The sensory effects provide the feedback or reinforcement for the action.

The net of neurons represented in Figure 6 illustrates that schemas exist at many different levels. There are tiny schemas embedded in small schemas. The small schemas are embedded into not-so-small schemas, which, in turn, are embedded in medium sized schemas, which are embedded in large schemas, which are embedded in larger schemas, which are embedded in humongous schemas.

At any level, sensory inputs can lead to switching schemas in or out of the active pattern. Tiny schemas deal with direct sensory inputs. Hence, they are likely to be part of many, many active patterns. Larger schemas deal with inputs from smaller schemas -- with perceived environmental features, objects, and situations. Large schemas can be concerned principally with anticipating sensory outcomes from complicated long-lasting performances. The active pattern at any given instant can include schemas from all of these levels.

In this sense, we can think of the brain as an extensive and elaborate switching system for organizing sensory inputs from environmental situations and for generating appropriate and properly timed responses to them; that is, it is an elaborate switching system for connecting stimulus inputs to response organs in such a manner as to have an anticipated effect on the environment.

Where are schemas located in our brains and how big are they? Changuex[7] makes some reasonable inferences, as follows:

> **One characteristic of the neuronal graph of a mental object is that it is both local *and* "delocalized." The mental object rests, to use S. Atlan's expression of 1979, "between the crystal and the vapor." Neurons interact in a cooperative manner, as in a crystal, but are dispersed like vapors throughout multiple parts of the cortex, with no simple geometrical relationship.**
>
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> **If there is something like ten million neurons per square centimeter of cortical surface . . ., and if only ten percent of these cells contribute to the percept, one still has something like a million neurons recruited (close to the number of axons in the optic nerve). If we now suppose that the pre-representations arise spontaneously from a similar number of neurons, then the number of possible combinations of a few million neurons scattered among tens of billions becomes enormous.**

Sensory Imagery.

Sensory imagery plays a very important part in our mental activity. Imagery occurs when somehow a schema is fired by some internal trigger rather than by an external stimulus and the schema does not trigger its usual movements. As Neisser says, imagery consists of our being able to split the perceptual parts of schemas from the response parts and to fire the perceptual part without having actual stimulus inputs from the outside world. How can this happen neurologically?

First, the perceptual part of the schema has to be fired by something other than sensory inputs. And this is certainly possible. It is easily conceivable that inputs to an assembly of neurons can come from either sensory nerves or from neurons in other parts of the brain.

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[7] Jean-Pierre Changeux Neuronal Man: The Biology of Mind. Translated by Dr. Laurence Garey. Published in the United States by Pantheon Books, a division of Random House, Inc. New York, 1985.

Originally published in France as *L 'Homme Neuronal* by Fayard.

Second, firing of the movement part of a schema must not occur if the schema is being used solely for its sensory imagery. Our previous blocked transmission pattern makes this also easily conceivable.

So it's neurologically conceivable for this extensive and complicated switching system to stimulate itself without external inputs. A schema can be cut-off from its environmental connections and be fired independently. It can become a schema for imaging or, if you prefer, imagining.

These imaging schemas can be activated by other schemas as well as by direct sensory inputs. There's no reason why such connections cannot be built. And the development of language provides reasons why they should be.

LANGUAGE AND MEANING.

Human beings use spoken language extensively and have done so for eons. Why do animals not speak? Is it because they do not have particular structures in their brains to manage language? Some linguists would have us believe so. But in recent years several chimpanzees and apes have been taught to use language effectively, although what they learned was not a spoken language. And, certainly, they have not learned to use language at the level at which we use language, but nevertheless they have demonstrated the ability to learn and use a form of language -- sign language or symbollic pictures.

So why don't animals speak? There is one very significant reason: They do not have an epiglottis that can provide proper breathing control for spoken language. Their failure to speak has nothing to do with their brains, but rather with the apparatus for producing speech sounds.

We usually think of language as being our basic means for communicating with each other. And, indeed, it is. But that does not mean that we developed our language ability in order to communicate with eachother.

The psychologist, Harry J. Jerison[8], views human language as constituting a supersensory system. He suggests that it developed initially within the individual as "a supplement to other sensory systems."

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[8] Harry J. Jerison "Evolution of the Brain" Chapter 2 in The Humen Brain by M.C. Wittrock et al. Prentice-Hall, Inc., Englewood Cliffs, N.J., 1977.

Why did early man need such a system? Jerison suggests that it was because we lacked the highly developed sense of smell possessed by many other animals. Consequently, humans had no way of marking a trail or a territory as do most other mammals. Jerison goes on to describe early man's use of language in this way:

> **I see the early use of language as a system for coping with an extended range** (that is, a large territory), **marking it vocally by identifying (naming) some features in it and vocalizing and hearing the vocalization. This could produce an internalized map of the range, and by the use of vocalization early hominids could identify and communicate their presence at distant parts of the range. . . . Such improved capacity for memory would enable the members of a group to reidentify a range or a trail from the restated calls or names, even if one assumes no improved capacity for storage, or memory, compared to that of other progressive mammals.**
>
> **The resulting picture is of wide-ranging predators using linguistic forms to map their range and territory. Early language contributed to the capacity for imagery rather than for communication.**
>
> **There is an interesting twist to this analysis. If we have a species in which imagery has auditory and vocal as well as visual and other sensory components, and if heard and produced and imagined sound is a central part of the imagery, a novel social behavior could evolve. By appropriate vocalization one animal in a group could evoke images of geographical maps or other events in other animals in the group. It is in such shared imagery, rather than communication in the usual sense, that I would identify the beginning of speech and language.**

If Jerison is right, then our lofty position in the order of things may be more due to our poor sense of smell and a very special epiglottis rather than to special structures in our brains. Our poor sense of smell forced us to devise an alternative to the typical method used by most other mammals for marking trails and territories.

The important part of Jerison's argument for our present purpose is his identification of language as a supersensory system. Our principal use of language, in Jerison's words, is to "produce complex images in our readers and listeners rather than to direct their actions."

Learning Language.

Consider how we learn our mother tongue. Infants are taught to say the names of people, objects, places, and actions. They see an object, they hear its name, and they say the name. In time, they simply see the object and say its name. They move to a place, such as the kitchen, and say its name. They run from here to there and then say their own name and the name of the action. The way in which infants learn language builds it right into the schemas they have for experiencing and acting upon the world around them. They see a place or an object and they say its name. Naming their own sensory images with words becomes a natural part of their perceiving the world around them.

Children also learn to use language to evoke sensory images in their own brains in the absence of the external stimuli for those sensory images. Others are also able to evoke images in the child through the use of spoken language. And, in time, the child learns to evoke images in others through the use of language.

Language would appear to be built right into our perceptual schemas rather than being a separate functional system. We often tend to think of the substance of our thoughts as being made up of words and symbols. Let me suggest that it is more accurate and more useful to think of our speech (including our inner speech) as a verbal description of the sensory images which are, in fact, the principal substance of our thoughts. Speech is often used to <u>initiate</u> thoughts, to <u>monitor and modify</u> thoughts during the act of "thinking," and as a means of <u>reading out the final product</u> of our thinking processes and for <u>communicating</u> that final product to others. But, in this view, the principal substance of thought is <u>sensory imagery</u>.

Finding the Right Meaning.

When we hear or read a word, how do we find the right meaning for that word? Do we activate one "meaning" after another until we find the right one for our present situation? That might be the way a computer would be

programmed to do it, but our neurons are much too slow to allow us to use a similar process. So how do brains find word meanings quickly?

To find an answer, let's digress a moment. Information in computers is measured in bits and bytes. A bit of information is a single binary choice -- a "yes" or "no," a "0" or a "1." A byte is the amount of information that a computer can process in the same instant. Most computers are serial processors. They process one byte of information containing from four to thirty-two bits at a time.

The brain, however, is capable of processing many, many bits of information in parallel all at once. Kent[9] notes that brains can process bytes containing a trillion or more bits. And we can have as many as a trillion or more trillion-bit bytes in our brain. So extensive and instantaneous "meanings" of words in terms of sensory imagery are no problem for the brain. And the imagery schemas that provide us with the meanings of our words can be very extensive.

Many words have a variety of meanings -- some very subtle. Many different imagery schemas are attached to the schema for hearing a word. But the context in which the word is heard determines which meaning will be activated when we hear the word. The context provides signals which inhibit some schemas and facilitate others. The context signals generally will already have acted on the brain before we hear the target word. Consequently, we rarely have trouble knowing what form of a word was intended or what meaning was intended for it. The context determines the proper meaning automatically. We can think of these as context switches which anticipate what will happen next.[10]

Context switches are also where our grammar resides. We don't have grammar rules stored in our heads that we search through to determine what grammatical construction to use. Grammatical choices are set automatically by our context switches. Most of us use pretty good grammar without even knowing the rules. And most of us have met someone somewhere who knew the rules but did not use good grammar.

Context switches can also activate extensive schema systems which prepare us to act in complex situations. A stimulus doesn't just activate a

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9 Ernest W. Kent The Brains of Men and Machines. BYTE/McGraw Hill, Peterborough, N.H., 1981.

10 See the discussion on stable states in William F. Allman "Mindworks" in the May 1986 issue of Science 86, American Association for the Advancement of Science.

single schema for a particular image, but rather it activates many related schemas. In this way, we are prepared to respond to entire situations on the basis of a single cue.

Areas in the Brain.

If language is a supersensory system that is built right into our other sensory schemas, how do we account for the existence of so-called language centers in the brain? Most of us have probably heard in a psychology course or two about Broca's area and Wernike's area (shown in Figure 7). Aren't these the areas where we have our word meaning and rules of grammar stored? And if not, then what are they?

Let me suggest that these areas are places where linkages are made between:

1. The schemas for organizing sounds and visual patterns into words and expressions.

2. The schemas for producing spoken and written expressions.

3. The schemas which set the context switches either for producing expressions or for assigning meaning to expressions, and so on.

The major parts of these schemas are dispersed throughout large parts of the brain. These areas of the brain are principally places where different kinds of schemas connect to each other. They are not centers where some kind of processing magically occurs.

Why should we believe that schemas are dispersed throughout large areas of the brain? In Figure 8[11] we see a series of brain scans showing the spread of activity in the brain of a person who was instructed to move his finger. That's a very simple act. The activity shown here only covers that portion of the act in which the person developed the intent to move his finger. It does not include the brain activity necessary to actually move the finger. As you can see, just intending to move your finger requires activity spread throughout a very large part of your brain.

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[11] From brain activity maps made by Jesse Salb. Taken from illustrations on page 74 of The Brain by Richard Restak. Bantam Books, 1984.

There is another reason that I discovered only recently. Back in the thirties, a Canadian neurosurgeon, Wilder Penfield, did the initial work of mapping the functional areas of the brain by means of electrical stimulation of particualar points in the brain. He did these experiments while doing surgery on patients to correct various neurological problems. Brain surgery is always done under local anethesia, so the patients were able to tell Penfield what they experienced when he stimulated some point in their brains.

He found, for instance, that if he stimulated a particular point in a particular patient's brain, the patient would start singing a particular song. Certainly, this kind of account of Penfield's work makes it sound as if particular memories were stored in particular places and stimulating them with the electrode caused them to be activated.

What in fact happened according to the authors of one popular book on the brain[12] was that Penfield's electrode electrically froze the area of the brain which it contacted. There was no electrical activity at the point of contact. The electrical activity occurred in remote but functionally related areas of the brain connected to the stimulated point. This account makes it sound much more as if Penfield was stimulating linkage points rather than storage or processing areas.

MEMORY.

Now we are at a good point to examine the concept of memory.

Psychoanalysis, pop psychology, and common cultural beliefs frequently allege that we have a record of every single event of our lives stored in our brains. These beliefs often imply that if we know how to go about it, we can recall anything that has ever happened to us or anything we have ever learned or known. These kinds of beliefs can seriously mislead an instructional technologist into expecting more memory capability from students than is reasonable and also into expecting students to remember and apply information that was not linked to its applications when it was learned.

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[12] The Diagram Group The Brain: A User's Manual. A Perigee Book published by G.P. Putnam's Sons, New York, 1982.

We do not store separate and perfect records of all of our experiences. Even the enormous capacity of the human brain would be taxed by such an attempt. And there is no evolutionary value in doing so.

How does a record of an experience gets made in the first place? We've got to have something to forget before we can forget it.

As we move through an experience, schemas are activated by sensory inputs from the environment and from the on-going environmental and cognitive contexts. These schemas generate sensory anticipations, exploratory and action movements, and anticipations of the sensory outcomes of these movements. If we have had similar experiences before, some very high level superschemas will be activated that integrate our over all perception of and performance in the experience. In addition, going through this particular experience will modify all levels of these schemas to some extent and to varying degrees.

If we have not had similar experiences before, then only lower levels schemas would be activated by the experience. But the experience itself connects and assembles these lower level schemas into superschemas for this particular experience. Recall of the event consists of activating this conglomeration of schemas either by some sensory inputs from the environment or by cognitive imaging.

Now we have built something we can forget. How does the forgetting happen?

First, let's note that the conglomeration of schemas used in our experience never did contain all of the sensory information that was available to us during the meeting. Schemas only pick-up and incorporate that sensory information which makes a difference in setting anticipations and in selecting actions. The initial record is incomplete: It does not include all the available information in the experience. We didn't need it so we didn't record it.

Second, many of the schemas that make up the superschemas have been used since then in other experiences and integrated into other superschemas. As a result, they have been changed at least in part. In a sense, the superschemas started getting changed and pulled apart by concurrent and subsequent experiences almost as soon as they were constructed. Bits and pieces of the record are eroded by being used in other experiences. Some are eroded almost right away.

Errors in recollection often occur because some of the schemas assembled into a superschema have been used in later experiences and changed as a result of such use. When the superschema (or what is left of it) is again activated, these smaller schemas are included in their modified form. In this way, pieces of later experiences can be mistakenly "remembered" as being part of an earlier experience.

Previous experiences can also affect what we remember about later experiences. The schemas we use during our meeting are modified through the "averaging" process. But when we use those schemas later on in reminiscing about our meeting, what is in the conglomeration of schemas is the average of all previous uses of each schema rather than just the sensory values from that experience alone.

How does this explanation of forgetting tie in to what we know about memory. In Anderson's popular text[13] on cognitive psychology, he arrives at the following recommendation towards the end of the chapter in which he reviews the basic concepts and principles of human memory.

> **A peculiar recommendation can be drawn from this chapter as to how to avoid forgetting. Often, not learning certain material can be beneficial. And forgetting certain material (or at least not rehearsing it) can also prove advantageous. As we have shown, material in memory can interfere with the acquisition and retention of other material that overlaps it. Thus, if certain material is not important it is best not learned or not rehearsed. This advice implies that to learn and retain what is important, we should lead rather austere lives, refraining from learning about the trivial or unimportant. . . . If one can accurately judge what is important and one is willing to pay the price of austerity in life, refraining from learning the unimportant could be an efficient way of remembering. . . .**

But if all this is so, then how is it that we sometimes remember an early experience in our life with great detail and clarity. Sharp, clear, long lasting memories will usually have one or more of these features:

1. They have some **highly unique aspects** to them that involve schemas not used in many other experiences.

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[13] John R. Anderson Cognitive Psychology and its Implications. W.H. Freeman and Company, San Francisco, 1980.

2. They involve some kind of **strong emotion**. Emotions involve strong sensory inputs from our own bodies. The uniqueness of these strong sensory inputs prevents the schemas of which they are a part from being used in everyday situations and, hence, protects them from modification. However, reinstatement of the emotion may be necessary for recall.

3. These memories may be detailed and clear -- and also **wrong**, at least in part. The schemas may have been radically changed by later events, but how can we "know" it?

4. The recollections have been replayed and **verbally rehearsed** many times since the event. We no longer "remember" the event itself, but rather we "remember" the images evoked by the verbally rehearsed description of the event. And the description and the images can be wrong.

Language as a supersensory system is a powerful adjunct in shaping human memories. We can make experiences more easily "remembered" by rehearsing the verbal parts of the experience and by formulating and rehearsing a verbal description of the non-verbal parts of the experience.

The words elicit sensory images and organize and strengthen them. We then describe the images with more words. Words and imagery interact to strengthen eachother. In this way, we build an "**imagery talk-about**" superschema that is more resistant to change than the natural superschemas built during the experience itself. The "imagery talk-about" is more easily rehearsed and, thus, the connections that hold the superschema together can be established more strongly. The "imagery talk-about" may be rehearsed hundreds of times for every single corresponding real event.

Imagery talk-abouts are the stuff of reminisence. We talk to ourselves almost constantly about the past, present, and future events of our lives. We use words to conjure up images and then describe the images with other words which conjure up yet other images.

We use the same processes used for reminiscing about our life experiences for "remembering" information learned in an instructional program. We build "imagery talk-abouts" that can be rehearsed and bolstered with other associations.

Students in a history class don't store "information" about some historical event or period. Rather, they learn to use their sensory imagery and inner speech to "image and talk about" certain characteristics of the event or of the period. Such "imagery talk-abouts" differ from life event reminiscing in that superschemas for the sensory imagery have not already been assembled in the brain. The verbal information obtained from the textbook and from the lectures has to be used to assemble such superschemas. These superschemas then become the means of generating imagery and speech during "recall."

Once we have learned to "image and talk-about" an event or topic, we can tie it to other topics we have also learned to "image and talk-about." We can describe characteristics of two events in inner speech and then compare and contrast the descriptions. We can describe them at different levels of abstraction.

We can use the abstract comparisons to generate new imagery schemas and then develop a whole new set of "imagery talk-abouts" based on this new imagery. And we can output to external scratch pads to develop outlines, flowcharts, Venn diagrams, and other devices which then become inputs for generating other more extensively integrated "imagery talk-abouts" in the brain.

The learning of knowledge in fact consists of learning a performance -- an "imagery talk-about" used to initiate, edit, and describe the related imagery schemas. This kind of activity makes up most of the "thinking" of which we are aware.

This view of how the brain works asserts that what we experience as "memory" is in fact a side effect of our building and modifying schemas for performing in the situations which are presented to us in our daily lives. Much of what is termed "knowledge" in this view consists of learning to "image and talk-about" various topics. Imaging and talking about something is a performance that students can be taught to do and the learning of it can be verified directly and simply.

So the next time you forget something, don't say, "I forgot." Instead say something like "I didn't rehearse it enough" or "I didn't form appropriate imagery" or "I didn't tie it to appropriate context cues" or "I've used parts of it elsewhere and now it's changed." These statements are a lot more accurate and will get you to thinking about how to prevent such occurrences in the future.

MENTAL FACULTIES, TRAITS, AND BUMPS ON THE HEAD.

There is a recurring and continuing temptation among teachers, trainers, developers, their institutions and their clients to avoid tough analyses and expensive instructional developments in favor of magical thinking and easy answers that don't work.

Sometimes these magical answers don't even come cheap. But no matter how much or how little a client spends on this magic, it's money wasted. This magic doesn't work because it's based on a false premise -- the premise of the faculty psychology of the Middle Ages. This premise asserts that there are faculties or "areas of power" in our heads which, like muscles, can be strengthened through exercise and that such strengthened faculties will then result in improved performance in all kinds of life activities. Classically, faculties have included powers such as will, reason, memory, emotions, perception, and imagination.

The attraction of this kind of thinking is that it leads us to believe that if we exercise our students in a few generic activities requiring application of a faculty, the strengthened faculty will generalize to a broad range of applications. Application of this kind of thinking in the past has led to advocating strategies such as:

1. Preparing students for a tough adult life by subjecting them to tough treatments during instruction. Supposedly this builds their grit and persistence. What it does in fact is interfere with the students learning the skills they need to function effectively in adult life and demoralizes most of them in the process.

2. Requiring students to study abstract mathematics to improve their general ability to reason. They learn abstract mathematics but don't improve their general ability to reason. And, of course, many fail the math course and wind up with diminished self-esteem.

3. Practicing students in creativity exercises to strengthen their creativeness on the job. They learn to perform better on the creativity exercises but they do not become more creative on their jobs -- for many different reasons.

Consider the latest instance of this nonsense: The supposed powers or faculties of the right brain versus those of the left brain. This is a resurrection of "creativeness" and "reasoning" faculties. Advocates of

strengthening the right brain's powers have taken legitimate research findings and twisted them into something that makes no behavioral sense and no neurological sense. A recent article in Psychology Today[14] has labeled it "neurobabble." And that is indeed what it is.

Behavioral Nonsense.

Let's look at the behavioral nonsense of the mental faculty argument first. It has a lot of attractions to it because it fits the ways in which we know people and describe them in our casual conversations: There is a substantial similarity between mental faculties and traits. For instance, we recognize that John is more "creative" than Nellie or that Bill is "lazier" than Nelson. These are convenient descriptive terms which we use to summarize and typify the behavior of another person. These traits, however, are descriptive variables not causal variables: They are terms invented by observers to identify some common characteristic which the observer sees cutting across a large number of performances. They are not "forces" or "powers" residing within the performer which produce his performances.

An introvert is not an introvert because he has a trait for introversion inside of him. We call him an introvert because he displays a preponderance of introverted ways of behaving in a broad variety of situations. Each of those introverted ways of behaving may have developed under entirely different circumstances. There is no evidence for believing that there is a common cause for all of these ways of acting. We are often surprised that such a person is not consistent in his introverted ways. But we didn't discover introversion in him, rather we invented a label which appears to typify his general way of acting.

If human effectiveness is not produced by faculties or traits or powers, then what does produce it? Basically, effectiveness in complex activities is the result of integrated habits. And habits are simply regularly occurring learned acts that are elicited by particular stimulus characteristics and which lead particular outcomes. That is, the causes of the occurrence of particular habits in a situation are the presence of particular stimulus characteristics and the occurrence of the anticipated outcomes in that situation. In addition, the performer needs to have gone through a series of experiences at some time in the past which led him to learn the appropriate habits and to integrate them in an effective manner. And the situation needs to be free of conditions which elicit competing habits.

[14] Laurence Miller "Neurobabble." "Books" column in Psychology Today, April 1986.

Habits are not restricted to just observable performances. We can identify and train mental habits and regularly do so. In fact, it's not really useful to divide habits into mental or cognitive habits and perceptual-motor habits, since virtually all useful habits contain significant elements of both. For instance, in stroking a tennis ball there is mental imagery involved in anticipating and "feeling" the flow of the stroke, the impact of the racket with the ball, and the follow-through of the stroke. And this imagery can be practiced mentally and such practice can lead to improvements in performance. And time spent in just mental practice can can often lead to a greater improvement than the same amount of time spent in full performance practice. Mental practice provides many more trials in the same amount of time than performance practice. But it is not a complete substitute for performance practice.

Neurological Nonsense.[15]

Now let's look at the neurological nonsense in the mental faculty argument. The advocates of right brain training speak as if we have two independent brain hemispheres in our head. They are independent only in the very special people on whom the split brain research was done. In normal people, the two hemispheres of the brain are connected by a thick neurological bridge called the corpus callosum. There are about 300 million nerve fibers in the corpus callosum and it normally transmits many millions of signals per second all the time. So you see, normal people hardly have two independent brains. What they have are two similar looking hemisphere that are physically and functionally connected and constantly sending signals from one to the other in both directions. An active pattern of neurons can cut across from one hemisphere to the other and back again many times over.

It so happens that somewhat different kinds of neural connections are made in the two hemipheres. But that's no more significant for performance technology than the fact that front wheel drive automobiles have the engine on one side and the transmission on the other. They are connected to each other. If that connection is severed, the automobile won't run the way it ought to. But we don't subject normal automobile's to transmission training to improve their creative traversing of roadways.

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[15] For an excellent survey and review of split-brain research, see Sally P. Springer and Georg Deutsch Left Brain, Right Brain. W.H. Freeman and Company, San Francisco, 1981.

What kinds of neural connections would have to exist in the brain if we had mental faculties? The area in which the faculty resides in the brain has to be connected to sensory processing schema representing all the possible situations in which the faculty might be used. Certainly its conceivable that such an area can have many, many connections, but how did they get developed without the kind of practice that causes those connections to be fired and strengthened?

There's an even more perplexing neurological issue. How can firing the connections required to perform in a few examples of a faculty wind up strengthening all of the connections? The notion of mental faculties assumes that <u>any</u> practice strengthens the whole faculty.

I'm not saying that transfer <u>from</u> the classroom <u>to</u> the job doesn't occur. Of course it does. But as most of us in this business know, it takes a very solid front-end analysis and instructional design to get effective transfer from the classroom to broad job practice. <u>It doesn't just happen</u>. You have to work hard to get it. And sometimes it requires considerable ingenuity.

Getting transfer means that we have to identify the skills required for effective performance and the common or critical characteristics of the situations in which the skills are used that elicit and shape them and the anticipations and consequences that drive them.

Creativity Incentives.

But before we become concerned with giving our people "right-brain creativity" training of either a generic or specific nature, there are some other questions we ought to ask about the incentives in the workplace for "creativity."

"Creativity" always involves some level of risk. If nothing else, the creative person is exposing himself to failure and to ridicule. Have we reduced the risk for undertaking creative acts? If the workplace provides punishing consequences for creative acts, all the creativity training in the world will <u>not</u> lead to improved creativity.

Does the workplace support or punish creativity?

1. To what extent are creative efforts in an organization evaluated on the quality of the solution rather than on whether it worked or failed? In many organizations, a creative failure can ruin a career

but not trying to solve a problem at all can lead to standard promotions.

2. To what extent are supervisors and colleagues skilled at providing constructive criticism rather than destructive nit-picking? Nit-picking is encouraged by highly competitive career advancement practices. Cut-throat competition for promotions can actually drive off the "creative" people and promote the nit-picking destroyers. This may be where we need to direct our training efforts.

3. To what extent are individuals provided support for long-term creative efforts? Useful creativeness in most fields usually results from long term cognitive persistence. It requires an individual to build up a body of issues and insights over a period of months or years. But if his job assignments are continually changing, little opportunity exists for that to happen. Are workers given some reasonable portion of their time that they can use to pursue their own work interests and receive reasonable support of those interests?

4. If an individual makes a successful creative effort, is he justly recognized and compensated for it? If my great idea is credited to my supervisor, I'll guarantee that's the last great idea I'll have on that job with that boss.

5. Is there a parallel non-managerial career track for creative technical people. Or can they advance only by giving up what they do best and probably like best to do.

6. Is the next generation of "creative thinkers" provided with effective modeling from the already established "creative thinkers" in the organization? Having a few Einsteins in an organization is not effective modeling. The novices have to be given a chance to interact with the masters in a way that's lets them perceive the how the master thinks - - from problem definition to idea getting to setting criteria for good solutions. Is there a mentoring program for developing "creative thinkers?"

So you see, there's are lots of questions to be answered and lots of programs to be undertaken before we even consider a "creativity" training program. And until we address these other issues, chances are that even highly specific, quality "creativity" skill training cannot possibly make a noticeable impact on actual job practices.

IMPLICATIONS.

What implications does all this have for the practice of instructional technology? Here's the bottom line.

1. Since brains are principally concerned with directing our movements through the situations we encounter in our environment, instructional programs should be designed to prepare students to perform effectively in future life and job situations. As far as brains are concerned, there is no difference between training and education.

2. The principal contents represented in the brain's schemas are sensory inputs -- from life and job situations and from the outcomes of performances in those situations. If we want people to perform effectively in future situations, then we must build appropriate sensory representations into the schemas they will use when they are actually in those situations. The only way to do that with our present technology is to have students actually practice the appropriate performances in the relevant situations or in effective simulations of those situations.

3. The learning of "knowledge" consists of learning to "image and talk about" relevant topics. If it is intended that such "knowledge" play a significant role in the students' lives beyond simply passing a test, then such "imagery talk-abouts" must be derived from the future performance situations in which they will be applied; they must be designed to elicit appropriate supporting imagery; and they must be practiced in appropriate performance situations under appropriate feedback conditions during learning.

Good performance-oriented instructional developers already do all of these things for different reasons. This view of how brains work strengthens the reasons for these practices and helps us ward off the misdirecting influences of psychobabblers, neurobabblers, and computerphiles. It's like having a little cognitive wolfbane on a string around our neck.

FIGURES

HOW BRAINS WORK

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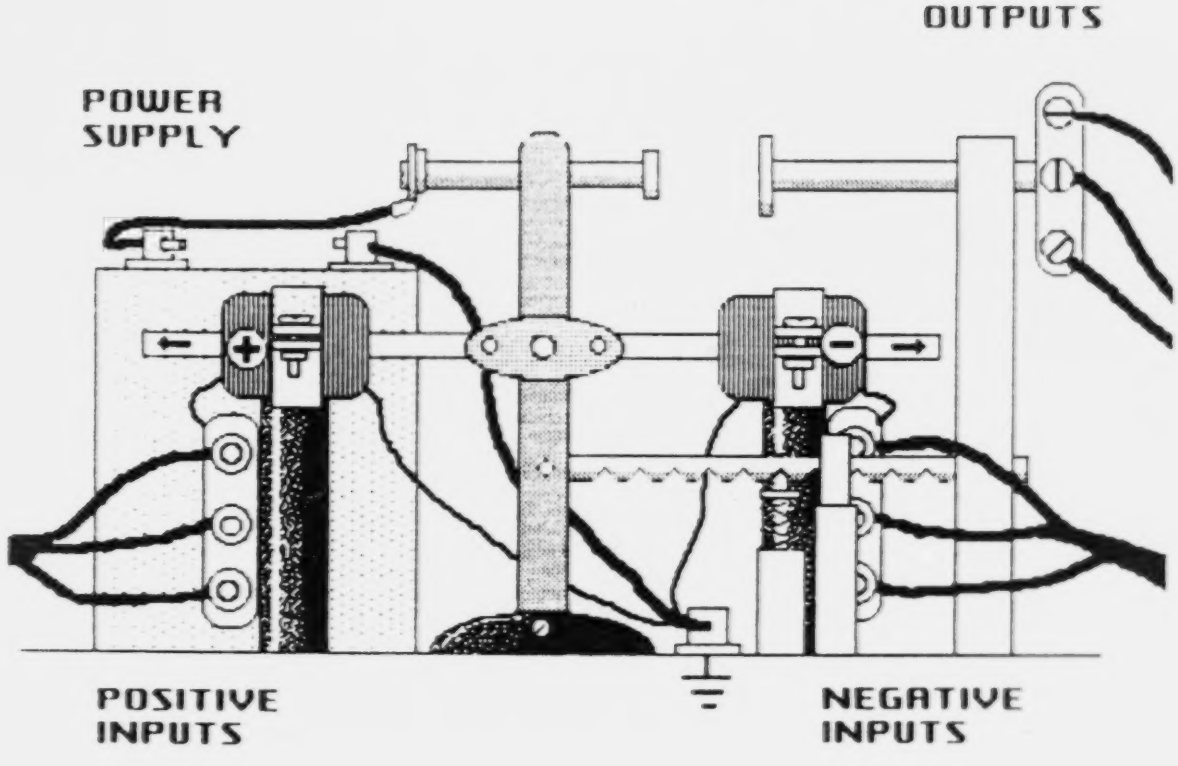


FIGURE 1. NEURON SWITCH

FIGURE 3. BASIC NEURON PATTERNS

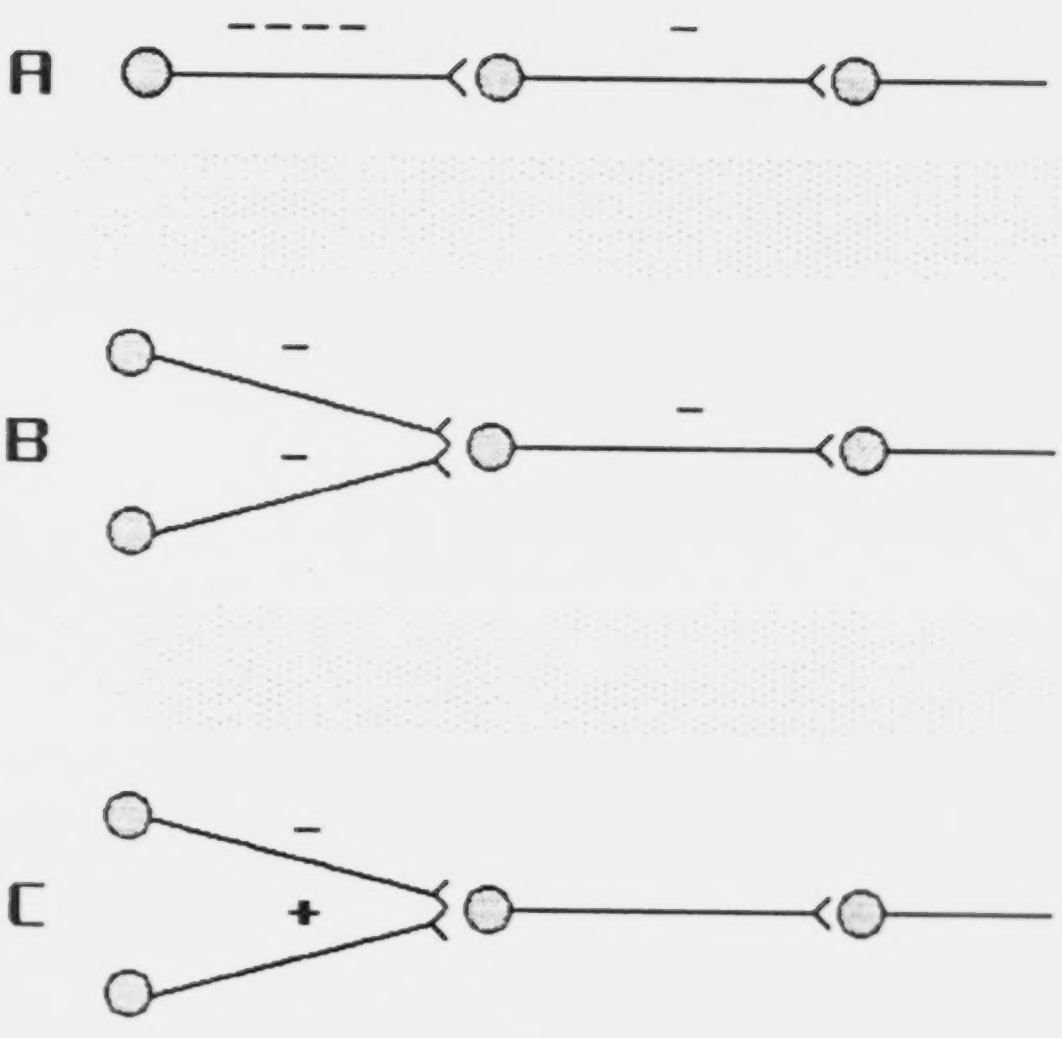


FIGURE 3. BASIC NEURON PATTERNS [CONTINUED].

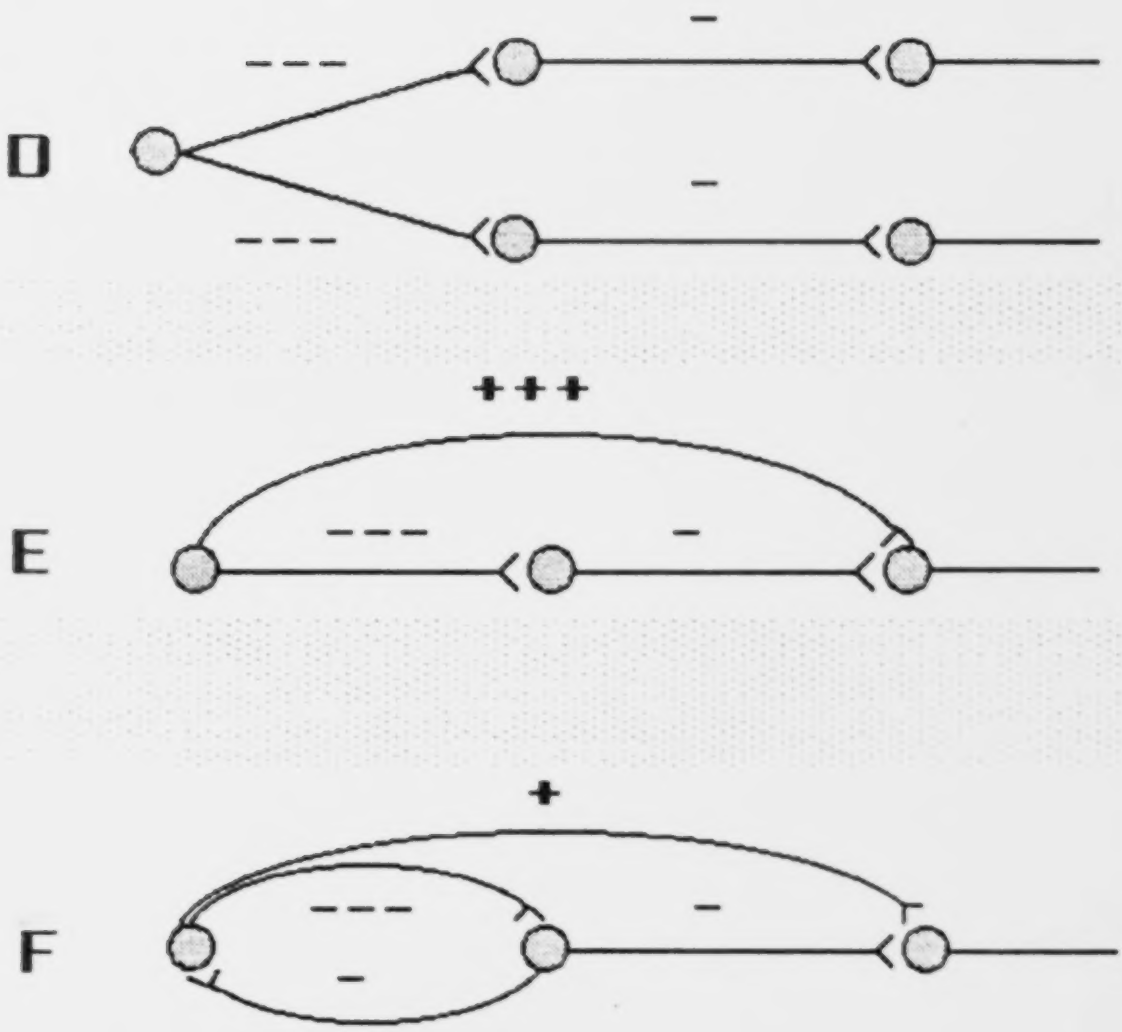


FIGURE4. NEURAL REPRESENTATION OF A SCHEMA.

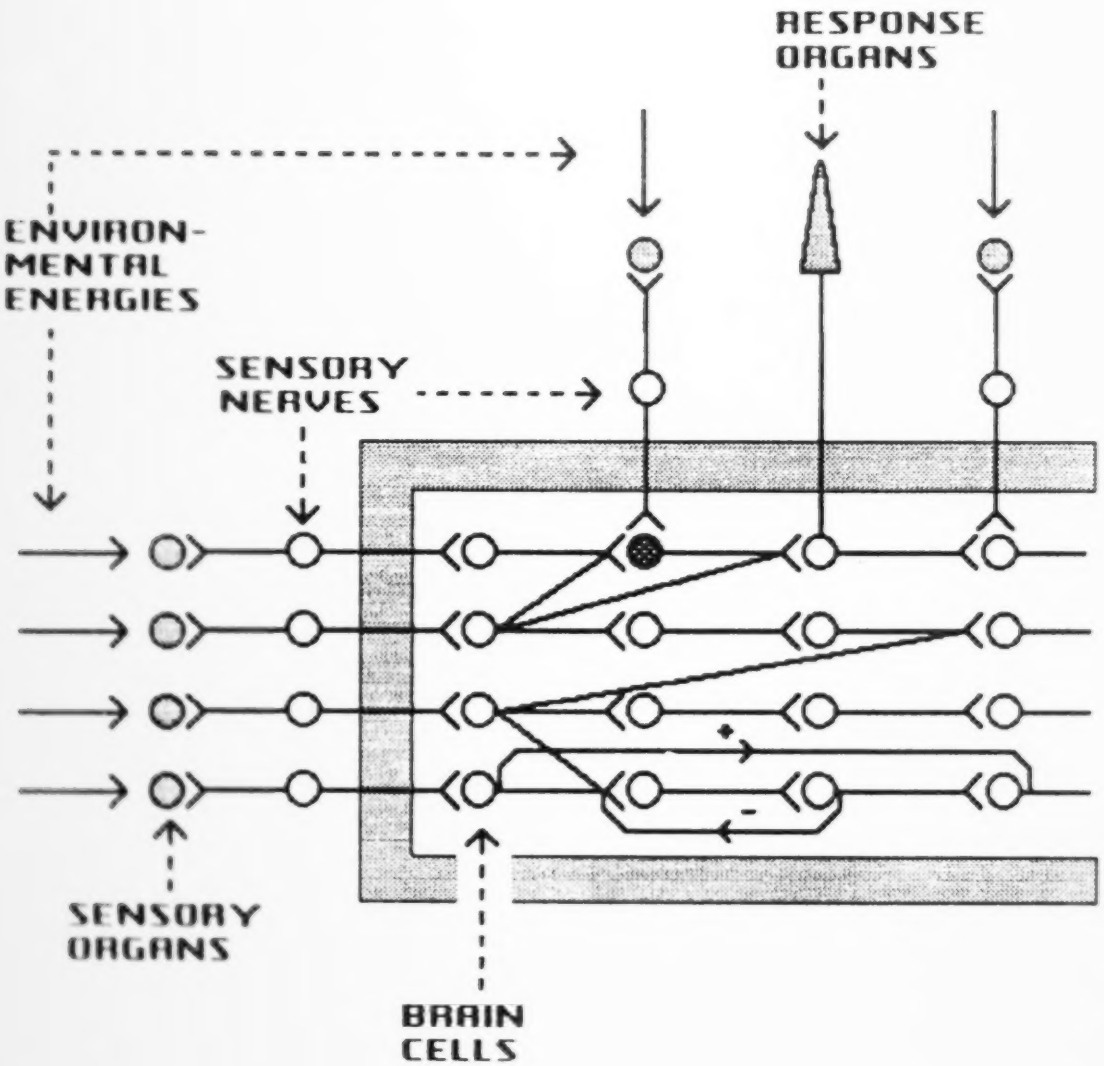


FIGURE 5. SCHEMA PROCESS

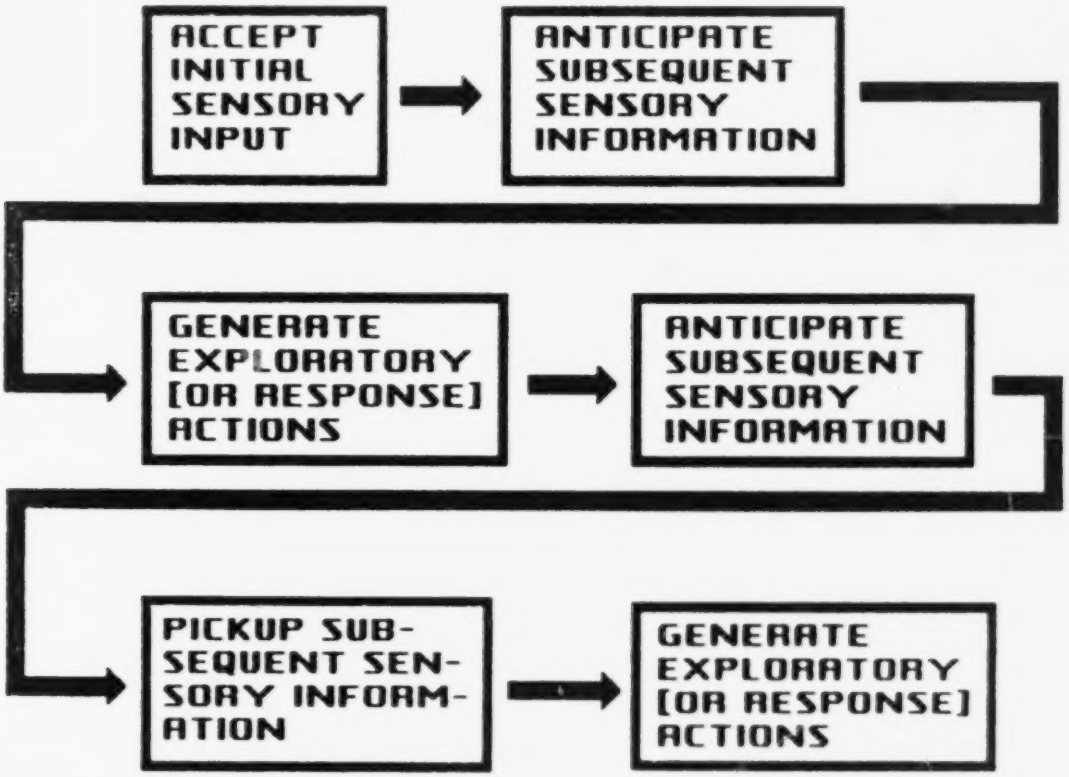

ACCEPT INITIAL SENSORY INPUT
ANTICIPATE SUBSEQUENT SENSORY INFORMATION
GENERATE EXPLORATORY [OR RESPONSE] ACTIONS
ANTICIPATE SUBSEQUENT SENSORY INFORMATION
PICKUP SUB-SEQUENT SEN-SORY INFORM-ATION
GENERATE EXPLORATORY [OR RESPONSE] ACTIONS

FIGURE 6. SCHEMA ORGANIZATION

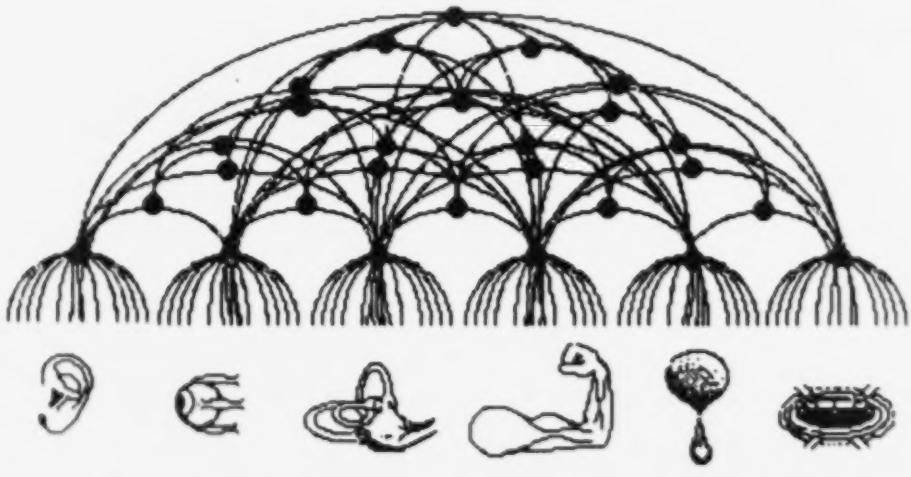


FIGURE 7. AREAS IN THE BRAIN

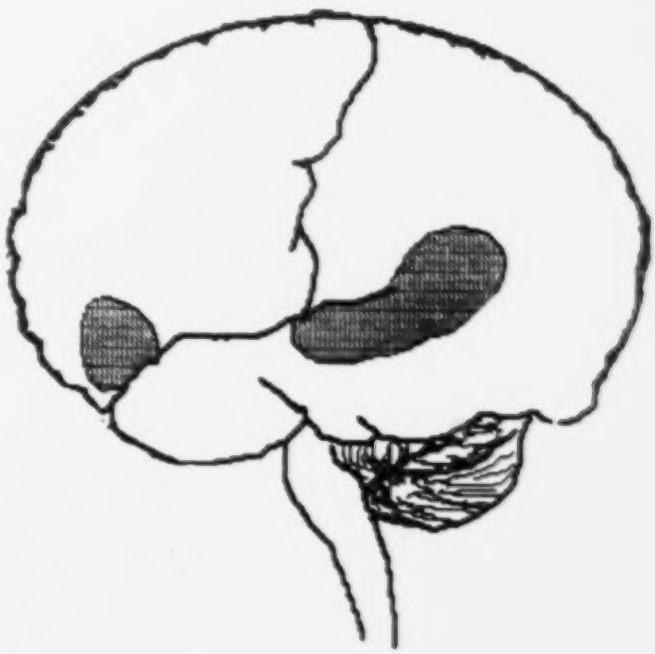
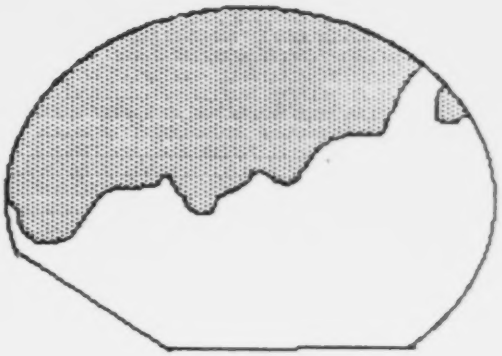


FIGURE 8. BRAIN ACTIVITY



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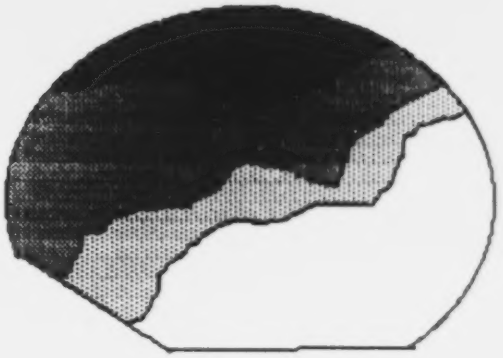

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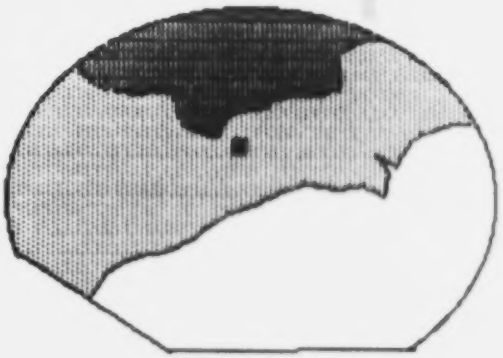

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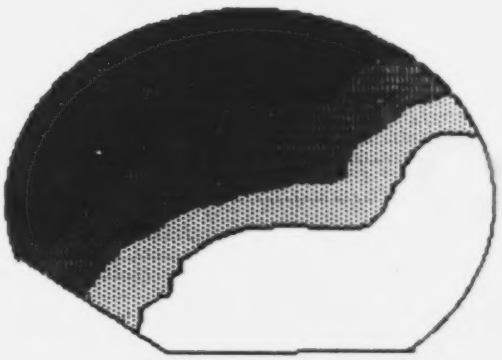

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